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RESEARCH REPORT

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ANALYSIS OF EMISSION DATA FROM A PERKIN-ELMER 1710 FTIR SPECTROMETER

ADRIAN TUDINI and SOI-SANG TI

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ANALYSIS OF EMISSION DATA FROM A PERKIN-ELMER 1710 FTIR SPECTROMETER

Adrian Tudini and Soi-Sang Ti

ABSTRACT (U)

The principles of analysis of radiant output of an emitter in the atmospheric spectral windows using a Perkin-Elmer 1710 FTIR Spectrometer equipped with an emission accessory are presented. From the raw emission data, experimentally measured for standard blackbody sources, the radiant intensities were analysed using the principles discussed. The analysed results are in good agreement with those theoretically calculated.

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1 INTRODUCTION

In the measurement of infrared signatures of military platforms, broadband radiometers have been extensively used. The broadband radiometer primarily measures the **temporal** profile of the emitting source over the spectral passband dictated by the spectral filter and the detector selected for the radiometer. Since a single integrated output is obtained from the radiometer over the entire broad waveband, the spectral property of the emitter is lost. Moreover, in the quantitative analysis of the radiant output of the emitting source, significant error arises if discord of the spectral profiles exists between the calibration source and the emitting source [1, 2].

With the development of more sophisticated IR guided missiles which exploit the spectral emission properties of the aircraft and ship target, there is a growing need to obtain the **spectral** profiles of the target platforms to be protected, so that effective countermeasure devices can be designed and developed.

The spectral profile of an emitting source can be conveniently and advantageously measured with an interferometer.It also provides a relatively easy means to quantify the radiant output of the source.

This document discusses the principles and derives the mathematical expressions from which the radiant output of an emitter can be accurately calculated from a Perkin-Elmer 1710 FTIR Spectrometer. No attempt is made to describe the operating principles of the instrument.

2 PRINCIPLES

Whilst the emissivity, $\epsilon(\lambda)$, of an emitter can be determined from the P.E. 1710 FTIR Spectrometer equipped with an emission accessory [3] and subsequently the radiant intensity, $I_S(\lambda)$, of the emitter evaluated, it is impracticable to set the same temperature for the emitter and the blackbody Moreover, in most cases the temperature of the emitter is unknown.If the intention is to only measure the radiant intensity of an emitter, a simple and convenient approach is needed.

2.1 Spectral Radiant Intensity in the 3-5μm waveband

When the spectral radiant intensity of an emitter is calculated in this region, the ambient contribution, which predominantly lies in 8.0-12.0μm region, can be assumed to be negligible. The spectral radiant intensity of an emitter is derived in [4] and is included here for completeness.

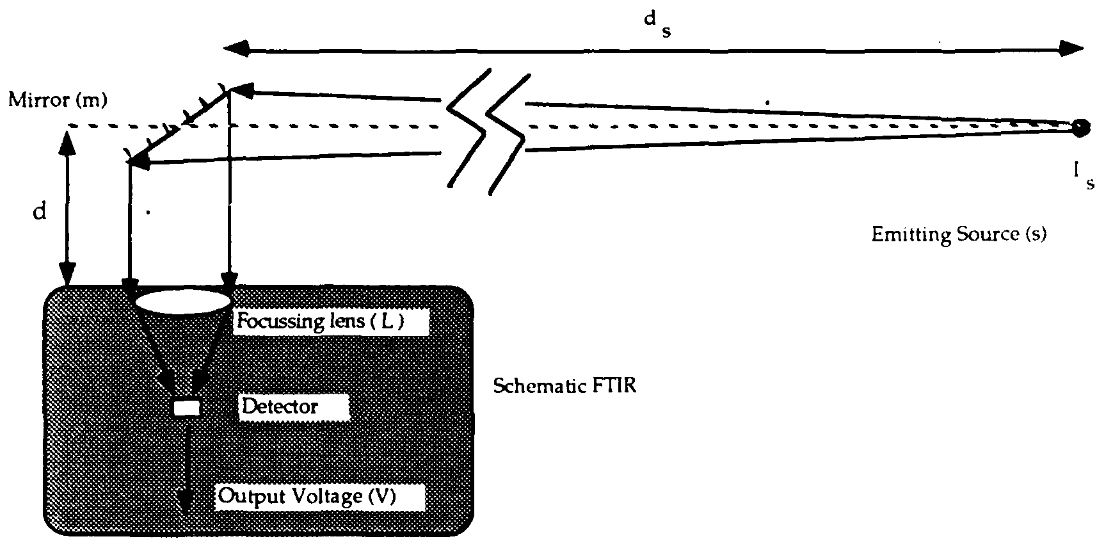


Figure 1 Schematic diagram to illustrate the derivation of radiant intensity of an emitting source.

The radiant flux arriving at the mirror of irradiated area A_m of the emission accessory, $\Phi_m(\lambda)$, is given by :

$$\Phi_m(\lambda) = I_s(\lambda)\,\frac{A_m}{d_s^2}\,\tau(\lambda, d_s) \qquad (1)$$

(see Figure 1), where $I_s(\lambda)$ is the spectral radiant intensity of the emitting source at a distance d_s from the mirror with reflectivity r (λ), and $\tau(\lambda,ds)$ is the atmospheric transmittance.

The radiant flux reflected from the mirror and collected by the focussing lens of surface area A_L, $\Phi_L(\lambda)$, is expressed as :

$$\Phi_L(\lambda) = \frac{r(\lambda)\,\Phi_m(\lambda)}{\frac{A_m}{d_s^2}}\,\frac{A_L}{(d_s + d)^2}\,\tau(\lambda, d) \qquad (2)$$

Substituting $\Phi_m(\lambda)$ from equation (1) in equation (2)

$$\Phi_L(\lambda) = r(\lambda)\,A_L\,\frac{I_s(\lambda)}{(d_s + d)^2}\,\tau(\lambda, d_s + d) \qquad (3)$$

The detector voltage generated is proportional to the radiant flux falling on the detector, as

$$V_s(\lambda) = k\Phi_L(\lambda)\,\varphi(\lambda) \qquad (4)$$

where k is a proportionality constant, and $\varphi(\lambda)$ is the wavelength dependent instrument response. The plot of $V_s(\lambda)$ versus λ is the normal infrared spectrum of the emitting source.

Substituting equation (3) in equation (4) :

$$V_s(\lambda) = k\, r(\lambda)\, A_L \frac{I_s(\lambda)}{(d_s + d)^2}\, \tau(\lambda, d_s + d)\, \varphi(\lambda) \qquad (5)$$

For the determination of absolute radiant intensity of an emitting source, a blackbody of a known temperature is used as a calibration standard. The infrared spectrum of the black body is then written as:

$$V_b(\lambda) = k\, r(\lambda)\, A_L \frac{I_b(\lambda)}{(d_b + d)^2}\, \tau(\lambda, d_b + d)\, \varphi(\lambda) \qquad (5a)$$

where d_b is the distance of the black body from the mirror of the emission accessory.

For $d_s \gg d$ and $d_b \gg d$, $(d_s + d)^2 \rightarrow d_s^2$ and $(d_b + d)^2 \rightarrow d_b^2$

Combining equations (5) and (5a) and simplifying :

$$\frac{V_s(\lambda)}{V_b(\lambda)} = \frac{d_b^2\, I_s(\lambda)\, \varphi(\lambda)\, \tau(\lambda, d_s)}{d_s^2\, I_b(\lambda)\, \varphi(\lambda)\, \tau(\lambda, d_b)} \qquad (6)$$

It must be noted that equation (6) involves the spectral profile, at each wavelength. For any identical wavelength, $\varphi(\lambda)$ disappears. To obtain $I_s(\lambda)$, equation (6) is rearranged as :

$$I_s(\lambda) = \frac{d_s^2}{d_b^2}\, I_b(\lambda) \frac{V_s(\lambda)/\tau(\lambda, d_s)}{V_b(\lambda)/\tau(\lambda, d_b)} \qquad (6a)$$

Clearly, the radiant intensity of an emitting source in a waveband λ_1 to λ_2 is the integral of $I_s(\lambda)$:

$$I_s(\lambda) \Big|_{\lambda_1}^{\lambda_2} = \int_{\lambda_1}^{\lambda_2} I_s(\lambda)\, d\lambda \qquad (7)$$

2.2 Spectral Radiant Intensity in the 8-12 µm waveband

The spectral radiant intensity of an emitter in the long waveband, ie the 8-12 µm region, can be similarly determined, but the contribution of the ambient radiation which becomes significant must be considered.

2.2.1 Low external background radiation

For a low external background, the radiation predominantly comes from the internal source in the FTIR at ambient temperature. Since the Perkin-Elmer 1710 FTIR Spectrometer is basically an instrument that performs transmission measurements, the radiation coming from the internal source is optically focussed onto the detector.

Let $\Phi_0(\lambda)$ be the ambient radiant energy from the internal instrumental source arriving at the detector and the corresponding voltage output, $V_0(\lambda)$, of the detector is :

$$V_o(\lambda) = k\,\varphi(\lambda)\,\Phi_o(\lambda) \qquad (8)$$

$\Phi_0(\lambda)$ is a constant quantity, since the interferometer is purged. It must be noted that $\Phi_0(\lambda)$ is 180° out of phase with the radiation coming from an external emitting source [3]. If $\Phi_s(\lambda)$ is the total radiant energy from an external emitter arriving at the FTIR, then, the net energy reaching the detector will be

$$\Phi_s(\lambda) - \Phi_o(\lambda) > 0 \qquad (9)$$

The radiation energy collected by the FTIR can be expressed in terms of the radiant intensity of the emitter, $I_s(\lambda)$, as

$$\Phi_s(\lambda) = A_L \frac{I_s(\lambda)\tau(\lambda, d_s)}{d_s^2} \qquad (10)$$

where all the notations have their usual meanings. The voltage output of the detector, $V_s(\lambda)$, is proportional to the energy received :

$$V_s(\lambda) = k[\Phi_s(\lambda) - \Phi_o(\lambda)]\varphi(\lambda) \qquad (11)$$

Substituting equations (8) and (10) in equation (11) :

$$kA_L \frac{I_s(\lambda)\varphi(\lambda)\tau(\lambda, d_s)}{d_s^2} = V_s(\lambda) + V_o(\lambda) \qquad (12)$$

Following the same procedure, equation (12) can be written for a calibration blackbody with a known area and temperature, and an expression is derived for the spectral radiant intensity, $I_s(\lambda)$.

ie,

$$kA_L \frac{I_b(\lambda)\varphi(\lambda)\tau(\lambda, d_b)}{d_b^2} = V_b(\lambda) + V_o(\lambda) \qquad (13)$$

and hence

$$I_s(\lambda) = \frac{d_s^2}{d_b^2} I_b(\lambda) \frac{[V_s(\lambda) + V_o(\lambda)]/\tau(\lambda, d_s)}{[V_b(\lambda) + V_o(\lambda)]/\tau(\lambda, d_b)} \qquad (14)$$

Three points are to be noted :

(a) Only the emitting source reflects the external ambient energy, $\Phi_a(\lambda)$ into the FTIR.

(b) Is(λ) is a good approximation of $I_s(\lambda) + r(\lambda)\ \Phi_a(\lambda)$ for an opaque emitter with a low reflectivity $r(\lambda)$.

(c) When the contribution from the instrumental source is ignored equation (14) is identical to equation (6a).

2.2.2 High external background radiation

In many cases where measurements are carried out in the field, the external emitter may be situated amongst an intense external background. The spectral radiant intensity of the emitter is then determined by measuring :

(1) The voltage output of the FTIR for the intense external background only :

$$V_1(\lambda) = k\ \varphi(\lambda) [\Phi_1(\lambda) - \Phi_o(\lambda)] \qquad (15)$$

where $\Phi_1(\lambda)$ is the radiant energy of the intense external background arriving at the FTIR, $\Phi_0(\lambda)$ the radiation from the internal source, and $\Phi_1(\lambda) > \Phi_0(\lambda)$

(2) The voltage output of the FTIR for the emitter emitting in the intense external background is given by :

$$V_2(\lambda) = k\ \varphi(\lambda) [\Phi_2(\lambda) - \Phi_o(\lambda)] \qquad (16)$$

where $\Phi_2(\lambda)$ is the radiant energy arriving at the FTIR when the emitter is emitting. Note that $\Phi_2(\lambda)$ is the sum of $\Phi_s(\lambda)$ and $\Phi_1(\lambda)$, where $\Phi_s(\lambda)$ is the radiant energy of the emitter. Bearing this fact in mind, equation (16) becomes

$$V_2(\lambda) = k\ \varphi(\lambda) [\Phi_s(\lambda) + \Phi_1(\lambda) - \Phi_o(\lambda)] \qquad (17)$$

Expressing $\Phi_s(\lambda)$ in terms of the radiant intensity of the emitter and substituting equation (15) in equation (17) :

$$kA_L \frac{I_s(\lambda)\varphi(\lambda)\tau(\lambda,d_s)}{d_s^2} = V_2(\lambda) - V_1(\lambda) \qquad (18)$$

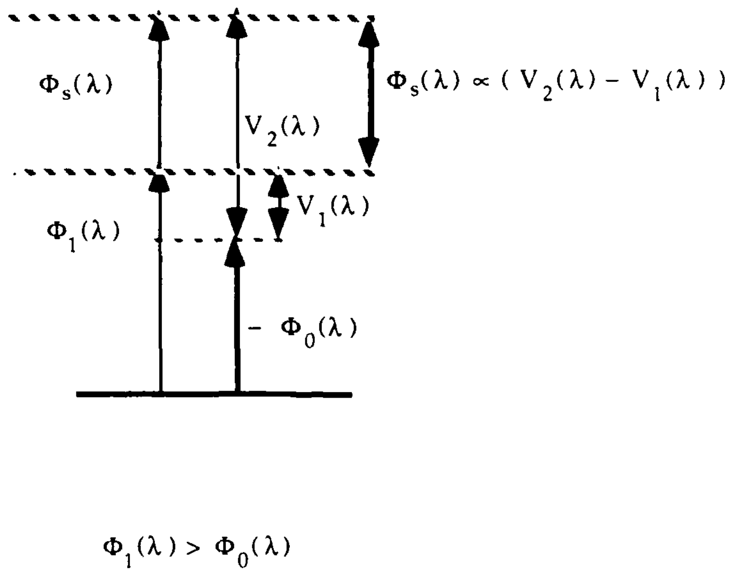
Equation (13) expresses the emission from a blackbody calibrated in a laboratory and where combined with equation (18), an expression is found for the spectral radiant intensity for the emitting source :

$$I_s(\lambda) = \frac{d_s^2}{d_b^2} I_b(\lambda) \frac{[V_2(\lambda) - V_1(\lambda)]/\tau(\lambda,d_s)}{[V_b(\lambda) + V_o(\lambda)]/\tau(\lambda,d_b)} \qquad (19)$$

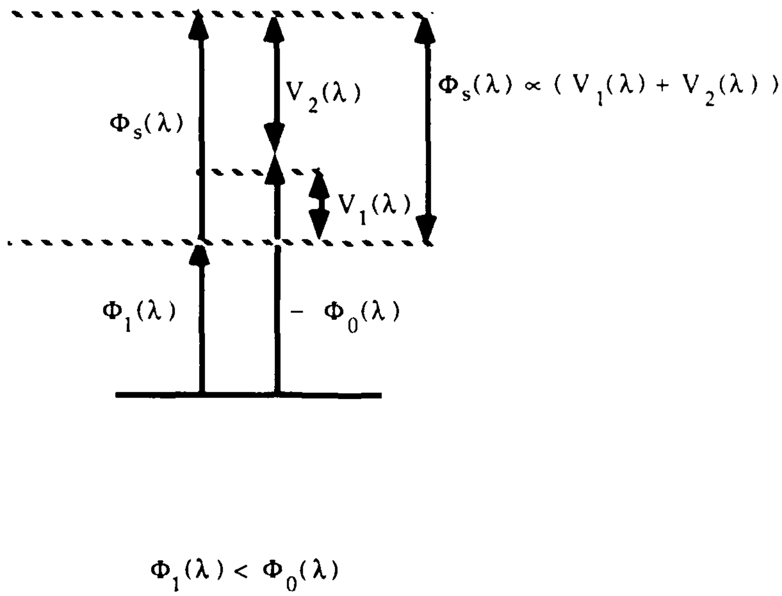
In the event of $0 < \Phi_1(\lambda) < \Phi_0(\lambda)$, the spectral radiant intensity of the emitting source is determined by

$$I_s(\lambda) = \frac{d_s^2}{d_b^2} I_b(\lambda) \frac{[V_2(\lambda) + V_1(\lambda)]/\tau(\lambda,d_s)}{[V_b(\lambda) + V_o(\lambda)]/\tau(\lambda,d_b)} \qquad (20)$$

Equations (19) and (20), are shown diagrammatically in figures 2 (a) and (b), respectively.



(a) For equation (19)



(b) For Equation (20)

Figure 2 Diagrammatic representations of Equations (19) & (20).

3 EXPERIMENTAL

A P.E 1710 FTIR equipped with an emission accessory and a collecting ZnSe lens ("The System") was used to record the spectral radiant intensity of an **Electro-Optical Industries Blackbody Radiator (Model WS144 SN597)**. The blackbody radiation was controlled by a temperature controller **(Model 205TSN597)**. The blackbody radiator had a radiating area of 81.07 mm^2 and together with the temperature controller, constituted "The Blackbody Unit ". The resolution of the FTIR was preset to 32 cm^{-1} and the experimental setup is shown below :

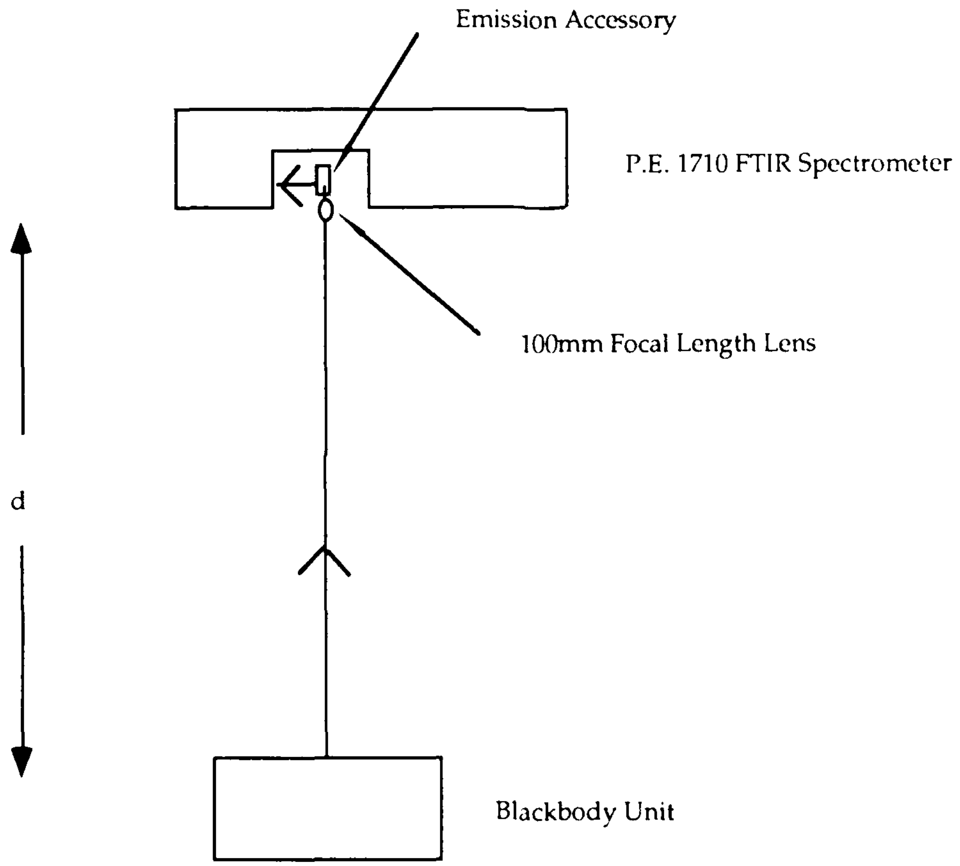


Figure 3 Experimental setup of the blackbody unit in front of the Perkin-Elmer 1710 FTIR.

The Blackbody unit was set at one temperature and its distance from the FTIR was varied .At each range, the IR radiation from the blackbody unit was recorded with the source aperture closed to give the background spectrum,and then with the source aperture open to give the resultant spectrum.In addition, the IR spectrum for the background without the blackbody unit present in the field of view (FOV) of the FTIR was also measured .

In the ensuing analysis, a blackbody source at an arbitrary range was chosen as the unknown emitting source and another as the blackbody calibration source. The spectral radiant intensity was analysed using the principles discussed and then compared to the theoretical value calculated at the same temperature using Planck's radiation law . (see Table 1)

Table 1 Distances between the blackbody unit and the FTIR and the blackbody temperature.

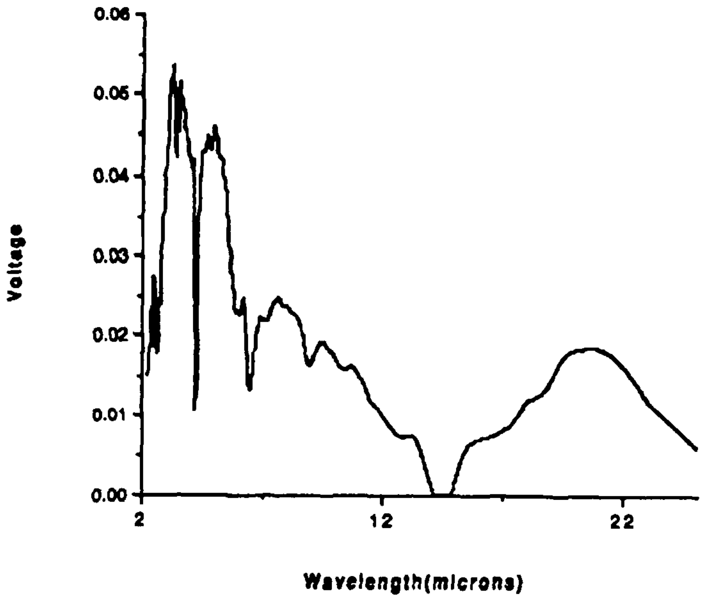
Blackbody Radiating Area	Blackbody Temperature	Blackbody Range
$81.07\ mm^2$	T = 1031.23° C	d = 1.24 m d = 1.43 m

For the FTIR to receive the maximum radiant energy possible, the emitting object must be along the axis of symmetry of the cone which defines the fixed FOV of the FTIR.The P.E. 1710 FTIR and emission accessory has an F/no. equal to 5.7 while the ZnSe has an F/no. equal to 1.8, hence, the P.E. 1710 FTIR will 'see' only part of the lens and the energy that is 'seen' is focussed onto the emission accessory mirror and then reflected into the interferometer. The ZnSe lens has a focal length of 100mm and it is placed in such a position that the mirror is at the focal point in the sample compartment. The distance between the lens and the emission accessory is considered to be negligible when the atmospheric transmittance is computed by the Lowtran 6 code.

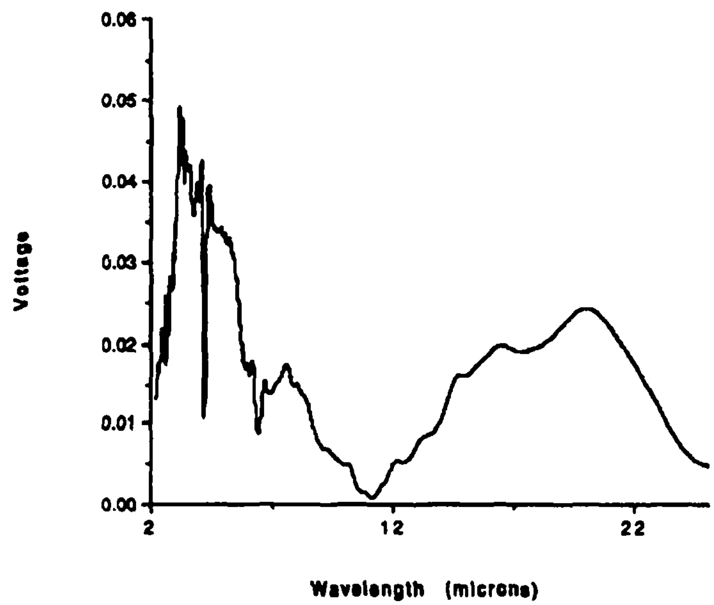
The alignment of the emitting source with respect to the FTIR is achieved using a **Hamatsu Solid State** camera which was mounted such that the principal axis of the FTIR is synchronised with that of the camera. Within experimental errors, a good synchronisation was achieved .

4 RESULTS AND DISCUSSION

The emission spectra of the Blackbody unit were measured at the preset temperature and at 2 different ranges (see Table 1). The recorded IR spectra are shown in figure 4. In the analysis, the blackbody source at 1.24m was chosen arbitrarily as the emitting source, and that at 1.43m as the calibration standard.



(a)



(b)

Figure 4 IR spectrum of a blackbody at a range of (a) 1.24m, (b) 1.43m.

Using the IR spectra in Figures 4 (a) and 4(b) for $V_s(\lambda)$ and $V_b(\lambda)$, respectively, the radiant intensity was determined by equation (6a). In this determination of $I_s(\lambda)$, no correction for the background was made, and the following result is shown in Figure 5.

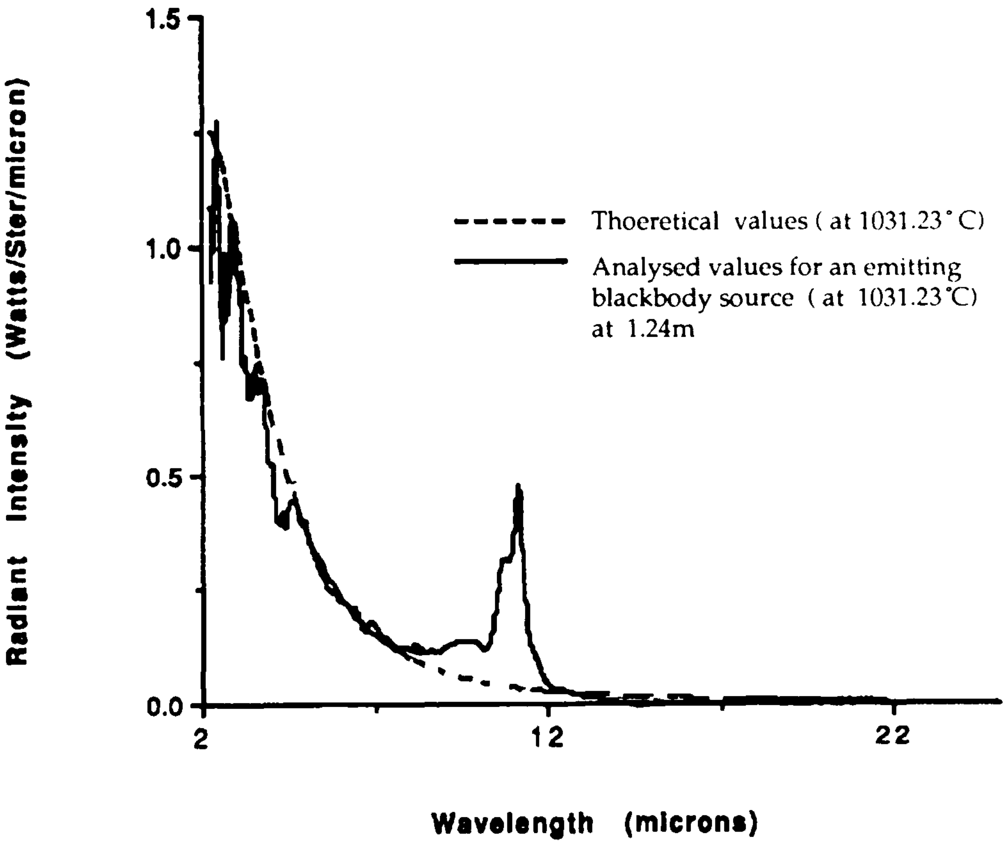


Figure 5 Spectral Radiant Intensity analysed for the emitting blackbody source (at 1031.23° C), without background correction.

It is clearly evident that spurious emission occurs only in the 7-12μm waveband, due to the ambient contribution which has not been corrected for. The analysed radiant intensity data in the 3-5μm waveband, however, are in good agreement with those theoretically calculated. Slight discrepancies occur in the regions near 2.6,2.7, 4.3, and 6.3μm, but are attributable to the inadequacy of the Lowtran 6 code to correct for atmospheric attenuation at very short range. The effects of the background contribution are clearly shown in Figure 6, which depicts the spectra measured with the source aperture on the blackbody unit closed.

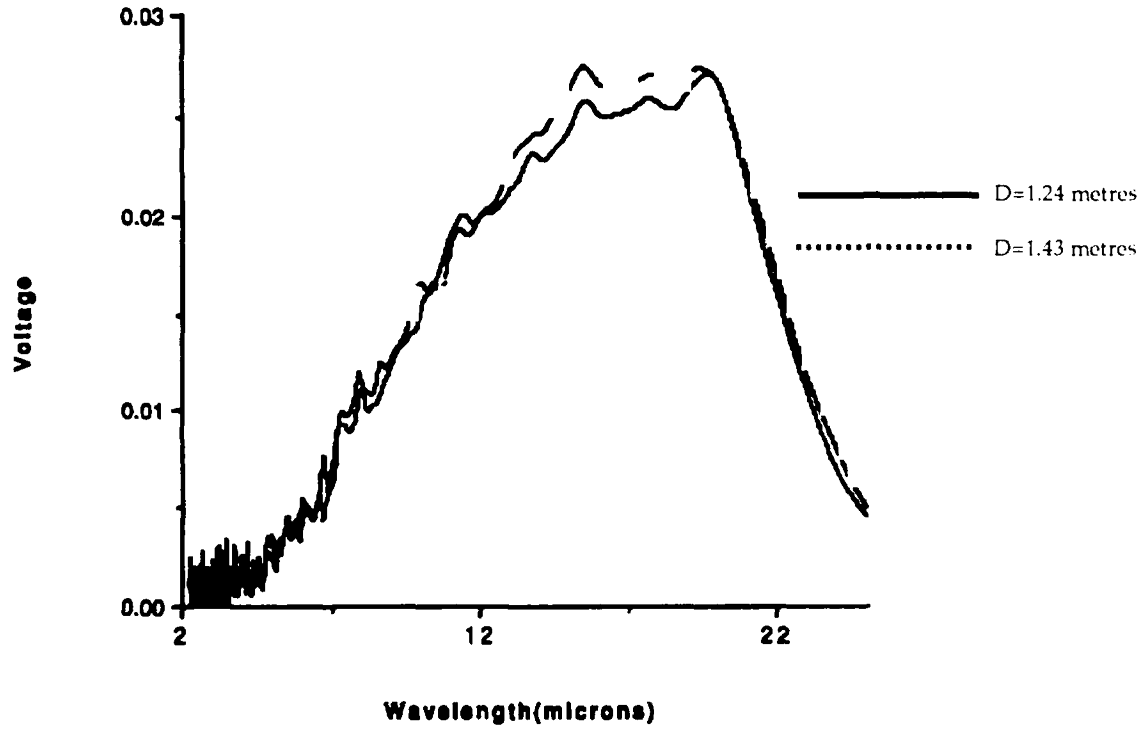


Figure 6 Background IR spectra of the blackbody unit at 1.24m and 1.43m.(Source aperture closed)

This background signal was essentially contributed by the instrumental source in the FTIR, verified from the spectrum recorded in the absence of the blackbody unit.When the analysis was repeated for the emitting source, but taking into account the background contribution, $V_0(\lambda)$, and using equation 14, the result is in accord with that theoretically calculated, as shown in Figure 7.

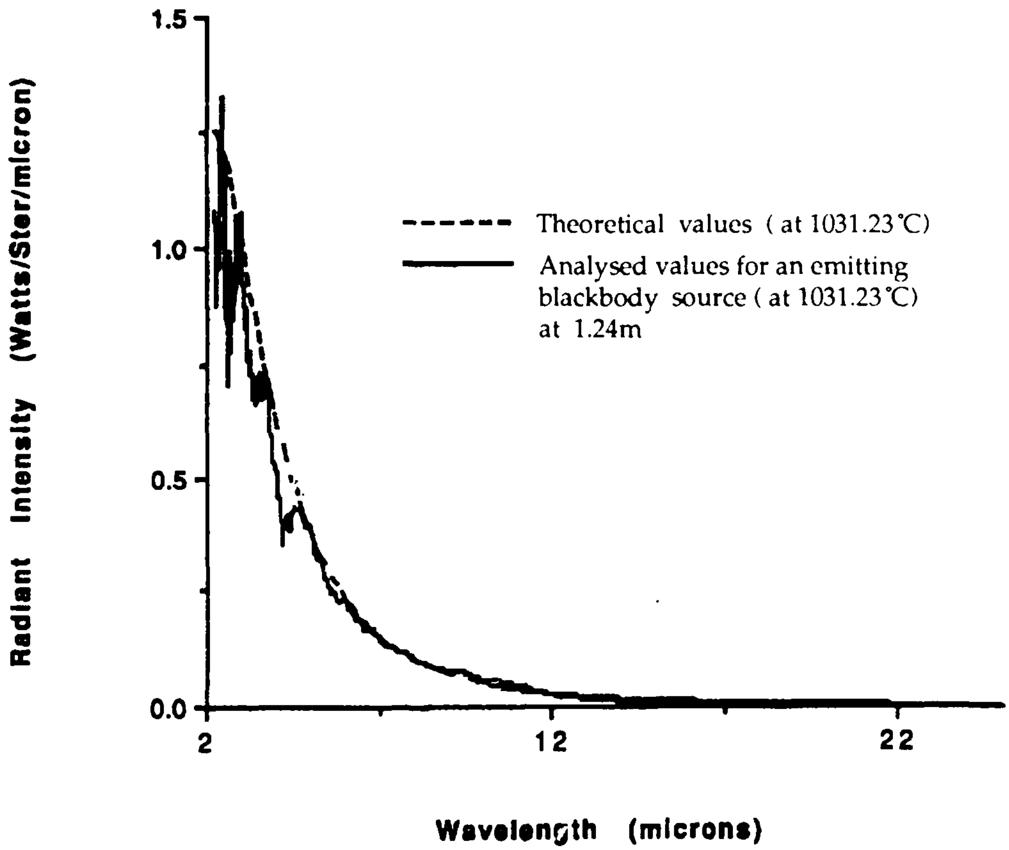


Figure 7 Spectral Radiant Intensity analysed for the emitting blackbody source (at 1031.23°C) with background correction .

5 CONCLUSION

Emission from a blackbody source was recorded by a Perkin-Elmer 1710 FTIR Spectrometer and the radiant intensity analysed for both the 3-5μm and the 8-12μm wavebands.

It was found that in the 3-5 μm waveband, the ambient contribution is negligible, whilst in the 8-12μm waveband, the ambient contribution is significant and must be corrected for.

The principles presented in this report provides a satisfactory means of determining the radiant output of an emitter, in both of the atmospheric windows, measured by a Perkin-Elmer 1710 Spectrometer adapted for emission measurements.

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17 SUMMARY OR ABSTRACT
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